Urban morphology and atmospheric pollutants distribution

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URBAN MORPHOLOGY AND ATMOSPHERIC POLLUTANTS DISTRIBUTION

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ABSTRACT

Influence of urban forms on pollutants distribution is presently investigated in urban atmospheric pollution researches. This multi-scale problem is generally studied on a single scale (local, meso or global) but seldom considering the total effect of network and urban units together. The articulation of several scales of pollutant observations (point measurement, streets, and urban area) is a particularity of the present work. Two objectives are defined:

precisely define the morphological elements which influence the pollutant distribution;

spatialize the measurements with the help of satellite data, taking benefits from previous results.

This research project allows the combination of different scales, different methods and modeling approaches on streets and on the total urban area through different geographical data integration (GIS and Remote sensing). The point measurement sites were also reviewed according the morphological indicators designed through GIS applications. The BD©TOPO-IGN allows extraction of heights, surfaces and volumes on the urban area, which are injected in pollution modeling, and used for qualifying the point measurement sites. These morphological indicators are associated to dominant winds (frequencies and charges) and studied in order to highlight the differences between proximity pollution and "day to day" one.

Such indicators need to be developed and tested in diverse situations to enhance the typology of measurement sites and strengthen their representativity.

INTRODUCTION

This paper reflects the work achieved for demonstrating the potential influences of geometric features on atmospheric pollutant distribution over metropolitan's areas. Several studies propose to analyze transportation and pollutants distribution processes in a global understanding rather than to consider only pollution heights [IVnS, 1999]. It implies to observe the daily exposure to pollution through a set of indicators allowing to enhance knowledge and estimation of urban pollution level and to disseminate results throughout populations and politic decision-makers. This study deals with such goals, observing air quality through the interactions between distribution processes and urban forms. The new European directive on Air quality promotes control and management of crisis situation in case of overlapping values of pollutants (30/12/1996) regarding European norms. Information has to be dispatched to alert the population in case of such situation and to stop or to push off course traffic transportation. To handle this situation, two objectives must be followed: the pollutant measurements must be defined at different scales and the pollutant distribution has to be spatialized. It means that over the urban area, we might be in position to locate pollution peaks, and also to represent areas that are exposed to a too high level of pollutant particles. This means to investigate more precisely (1) the building arrangements for urban air pollution modeling, (2) the streets network characteristics and (3) the links between these local elements and the global urban area (Weber et al., 2001).

Influences of urban forms on pollutant distribution are presently investigated in urban atmospheric pollution researches at few scales, from local to global urban area but generally on a single scale (local, meso or global). The merged effect of streets network and urban units are rarely studied. The interaction of several scales of pollutant observations (points-measurements, close surrounding area, streets and global urban area) is a particularity of this multi-scale work. This project is applied to the city of Strasbourg, France.
Its objectives are to:

- to precisely define the morphological elements, which influence the pollutant distribution;
- to spatialize the measurements with the help of satellite data, taking benefits from previous results.

Therefore this research project explores:

- the combination of different scales (from points-measurements to the complete urban community of Strasbourg);
- different modeling approaches (from a single street to the total urban area).

After a state of the art and the presentation of the studied area, the rational of the project will be precised. Some results will be presented and some questions will be tackled like the accuracy of the points-measurements sites definition. The categories of point-measurements sites are defined according to morphological and defined representativity indicators of the measurement sites (traffic site, industrial site, urban site, ADEME and EDM, 2000). The geographical database (BD© TOPO-IGN) is exploited for the extraction of parameters as inputs of the models of pollutants transport. A method combining remotely sensed data, provided by the Landsat Thematic Mapper (TM) sensor and the points-measurements, is presented, allowing the obtaining of a spatial distribution of pollutants over the city. This remotely sensed distribution is compared with usual methods (interpolation or extrapolation) used for the spatialization of pollutants. These methods for deriving spatial information on the pollutant distribution over cities are interpolation (whatever the interpolator operator) or extrapolation. But these methods did not take into account morphological aspects and structural characteristics of city of interest. Hence, influences of urban forms on pollutant distribution are presently investigated in urban atmospheric pollution researches. This approach enhances the benefits of using satellite information for the description of pollutants over the city. A discussion on the results of this research project is proposed enhancing benefits of a multi-disciplinary, multi-scale, multi-sensor approach of air pollution.

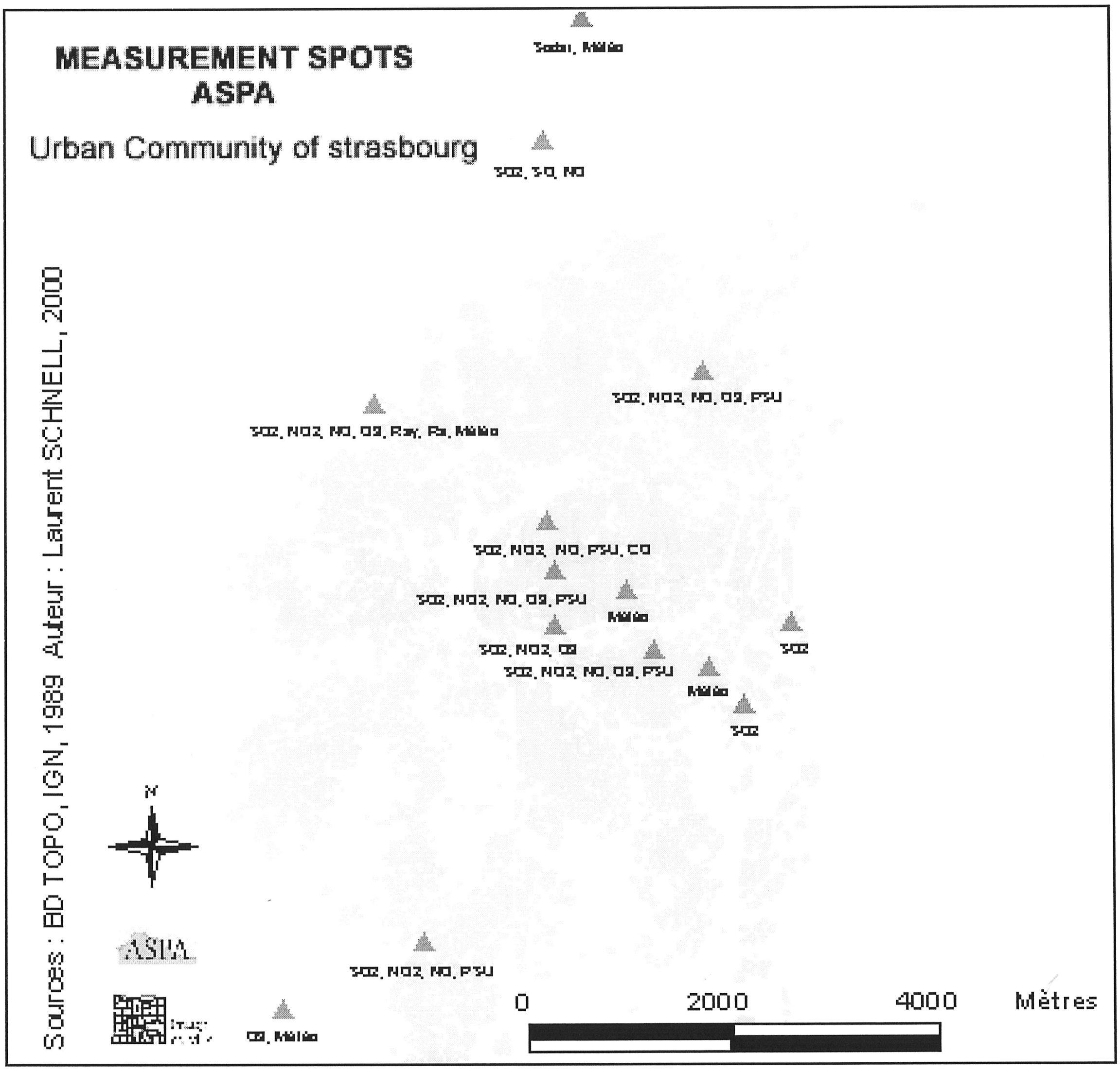
STATE-OF-THE-ART

The benefits of the decreasing SO_2 and NO_2 values since several years in European cities are erased by an overpass of the general norms fixed by the EU15. 37 millions of inhabitants are daily exposed to high pollutants values in European cities (among those which are equipped with measurement network) [EEA, 1997]. Such situations are not only representative of European countries, developing countries are also facing this problem. Climatic urban profile must be more analyzed than previously, in order to get not only a precise but also a located understanding over time, and also to define complementary spatialized measurements campaign events. The collected data would enrich the knowledge gathered over different observation scales: local to global. Legal requirements in France and Europe cover not only the pollutants diminution trends but also the exposure of population concerns. This position implies to observe the internal variability of pollutants distribution in cities. As such urban pollutant distribution needs rather adapted observation scales allowing studying internal variability and general urban area situation. Most of the transportation and distribution pollutant models developed according a 1*1km grid deal with the latest scale requirement. Large investigation scales are addressing one street or a build unit, few try to articulate large scale (the network of streets and the built up units) and the general urban area scale. To achieve this goal it seems to be worthwhile to identify and precise some elements (land cover, built density, etc.) at a rather local scale to enhance the larger scale results; the idea being that the interactions between scales might be highlighted through particular elements described from one scale to another. Thus a better understanding of pollutants distribution processes at different scales is developed through the design of some indicators (quantitative and qualitative) extracted from pollutants measurements network locations and street network analysis. These indicators are developed for comparison purposes and variability assessments in urban transportation pollutant studies. Thus, they are exploited as parameters of pollutant distribution models, especially the spatialization model based on remotely sensed data and the representation of pollution events according to public and legal obligations.

The aim of air quality monitoring is to get an estimate of pollutant concentrations in time and space. Several models exist and provide a map of pollutants concentrations by modeling its transport, deposition and/or transformation processes in the atmosphere. Those models are classified with regard to the scales of atmospheric processes. Spatial scales may range from the very local scale (e.g. street level, direct surroundings of a chimney) to the global scale (up to 100 km); time scale may range from minutes (estimation of peak concentrations) up to days (estimation of trends). Those models can be distinguished on the treatment of the transport equations (Eulerian, Lagrangian models) and on the complexity of various processes (chemistry, wet and dry deposition). Further descriptions of those models are given in a report of the European Topic Center on Air Quality (Moussiopoulos 1996). To evaluate the population exposition to air pollution, a mesoscale (urban scale) model is required. Existing models differ with regard to the structure of the computational domain, the utilized parameterizations, the method of initialization, the imposed boundary conditions and the applied numerical techniques. Such models require as input considerable meteorological, geographical information, and emission data. Hence they require numerical simulations, often in conflict with the limited data processing resources, and not enough accurate yet. Those model evaluations are impossible without appropriate experimental data at proper locations in Europe. The other ways to reconstruct the signal are models by means of interpolation and extrapolation of measurements. The problem is to reconstruct the spatial distribution of the pollutant considered within a geographical area, given limited values. Some scientists use the kriging method (Frangi et al. 1996, Carletti et al. 2000); some others recommend the use of the thin plates interpolation method (Ionescu et al. 1996). The quality of the maps can be judged by comparing predictions and appropriate measurements. But the validity and accuracy of such an approach depend on the number of measurements. It results that no accurate knowledge of the spatial distribution of pollutants, over a city, is accessible.

Air pollution in cities is a complex phenomenon involving local topography, local, wind flows and microclimates. For its better description and understanding, the study of its space-time variability should include different data sources related to urban morphological and environmental features. In this context, satellite images are certainly a valuable help in getting urban polluting features. Satellite imagery improves the monitoring of cities in a wide range of applications, e.g., mapping roads and streets (Couloigner 1998), mapping urban demarcation (Weber 1995), mapping of physic parameters such as albedo and heat fluxes (Parlow 1998), and also mapping urban air pollution (Basly 2000). Several studies have shown the possible relationships between satellite data and air pollution (Finzi & Lechi 1991, Brivio et al. 1995, Sifakis et al. 1998, Retalis et al. 1999, Wald and Baleynaud 1999, Basly 2000).

The city of Strasbourg is located in Eastern France at the border of Germany. L'Association pour la Surveillance et l'étude de la Pollution Atmosphérique en Alsace (ASPA) is the local organization in charge of the air quality measuring network in the city of Strasbourg and vicinity. The case of Strasbourg-France (306km^2) is interesting because a large set of measurement sites is spread over the area. 14 measurement sites are listed. The measurement network is rather old and provides time series data since about 1980 according to national typology requirements (figure 1). All the spots collect large or peculiar data sets.



▲ Localization of the measurements spots

CO	Monoxyde de carbone
NO2	Dioxyde d'azote
NO	Monoxyde d'azote
O3	Ozone
PSU	Poussières
SO2	Dioxyde de soufre
SO	Monoxyde de soufre
Ra	Radioactivité

Measured paramaters

Ray	Rayonnement global, diffus, infrarouge, ultraviolet A, direct et insolation
Sodar	Profileur de vent accoustique mesurant la composante des vents de 100 à 1200 m (Profil de vitesse horizontale, de direction, de turbulence et de température)
Météo	Direction et force du vent, température, humidité

Figure 1: Typology of the pollutants and particles collected by the measurement sites.

METHODOLOGICAL STEPS

The different steps developed in this study are complementary. The general process articulates observation and spatialization and anticipates the inputs/outputs the results might provide.
The various steps focus on the measurement sites description liable to allow comparisons, street modeling in order to get the particularities of pollutants behavior at the street network level and the spatialization of pollutant distribution over the urban area using remote sensing data.

Measurement sites description

The use of the third dimension to characterize built area and design geometric indicators introduces urban forms in the approach. The hypothesis here is that at a micro scale, forms have some influence on urban climatic profiles. Data sets collected (table 1) are numerous describing: measurement sites, buildings and streets, socio-economic data (population, density of population), traffic characteristics. Each building is described by the location coordinates (x,y) and the z value (height) in a geographical database (BD TOPO©IGN). The points-measurements sites were qualified according to morphological indicators. The geographical database was also exploited for the extraction of parameters as inputs of the models of pollutants transport (Schnell, 2000). The capacities of the GIS software (Arcview©3D analyst) allow obtaining a 3D representation of the measurement areas and also performing several spatial analyses over buildings or heights for instance.

Measurement data	Close surrounding area	Buildings	Socio-economic data	Street data
Meteorological Pollutant data	Land-cover Surface	Coordinates Volume Height	Population Density	Distance to nodes Traffic Orientation

Table 1: Measurement sites indicators.

Performing GIS analyses provide different indicators about measurement sites. These indicators will be used for two purposes: (1) the study of the representativity of measurement sites and its close surrounding area; (2) the extraction of parameters for " pseudostation " (Ung et al., 2001) in relation with the satellite data in order to describe as precisely as feasible the location and the associate spectral values. They have to be defined according comparison criteria among the sites of the same city but also regarding networks of other cities.

Sites measurements definitions

Two main types have been developed relying on usual collected values and geometry of urban forms over three " urban measurement sites " collecting PM_{10} measures. The first is associated to the general behavior of the collected date, meteorological data and pollutant information. They provide an idea of the variability of the sites values. The second deals more with geometric information due to urban forms and heights use. The three urban sites (Kleber, STG centre, STG Est) have been chosen for the characteristics of the location (near the center of the city) and the specificities of the urban forms of the close surrounding area (Durrenberger, 2001).

Urban spots descriptors

The meteorological trends provide general behavior of the measurements sites, their nycthemeral and seasonal rhythms. The land-cover data extracted from remote sensing data processing give information on the land-cover/use types associated with the measures location and allow considering the associate spectral values. The Z_0 layer provides information on roughness surface according a grid of 1 *1 km.

Geometric descriptors

In order to describe the close surrounding area and the possible relationships between forms and measured values, we have defined a peculiar surface (S) corresponding to the " visible " area from the measurement location and the total surfaces of the houses' fronts (f) concerned by the surface (Σf) (Schnell, 2000). Other types of information are collected like the number of streets connected and type of street. This type depends on the number of lanes, the height of buildings related to the width of the street, the type of buildings, etc. Another area has been taken into account, defined as the exposed population density inside a 1km radius around the location (A). This area have been divided into five embedded circles, each of them being able to allow extraction of data on building densities per distance, heights of buildings per distance and sectored information (figure 2).

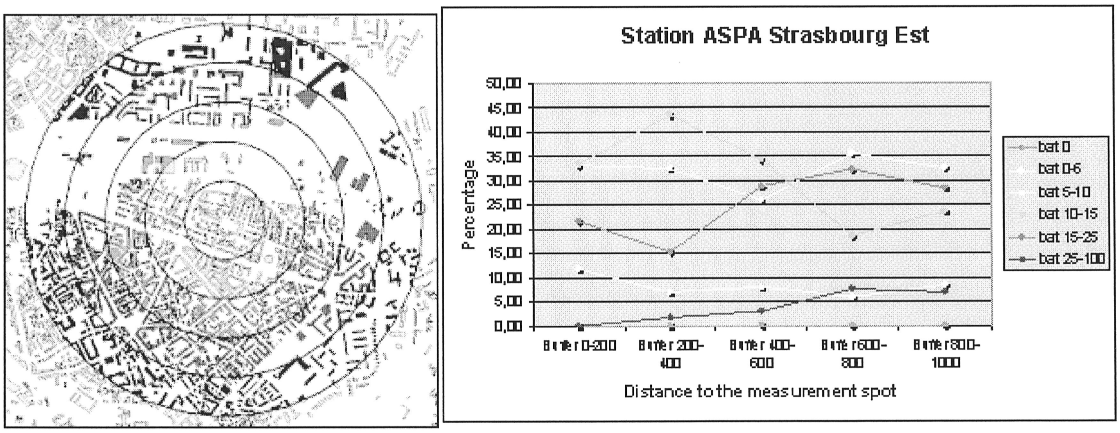
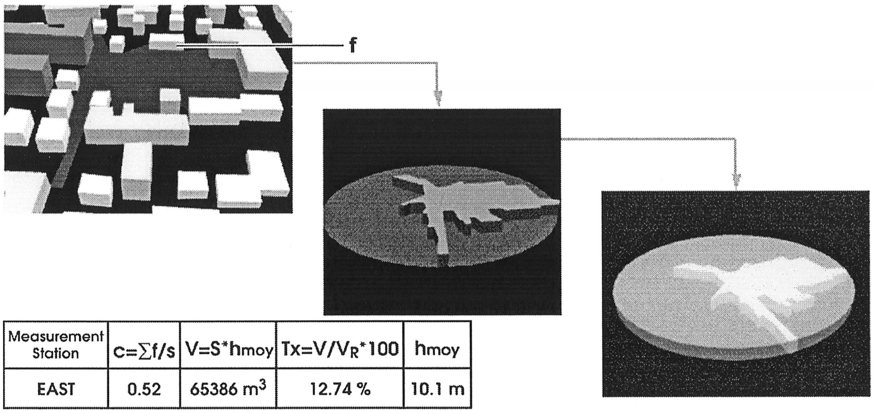


Figure 2: Geometric information on close surrounding area.

Volumes have been also used to describe the measurement spots. In particular they allow extraction of comparison features enabling to look at the difference between a stuffy volume or on the contrary an open one. Using a reference volume (V_R) = (Hmoy*A) where Hmoy is the mean height of the surrounding buildings) it is possible to obtain several indicators linked to urban forms (figure 3), like:
(V) related to S (Hmoy*S) and the form rate ($T_V = V/V_R*100$). These descriptors provide quantitative features that complete the observations on measurement spots.



Measurement Station	$c=\sum f/s$	$V=S{*}h_{moy}$	$Tx=V/V_R{*}100$	h_{moy}
EAST	0.52	65386 m^3	12.74 %	10.1 m

Reference volume ($V_R=A{*}h_{moy}$) : 513336 m^3

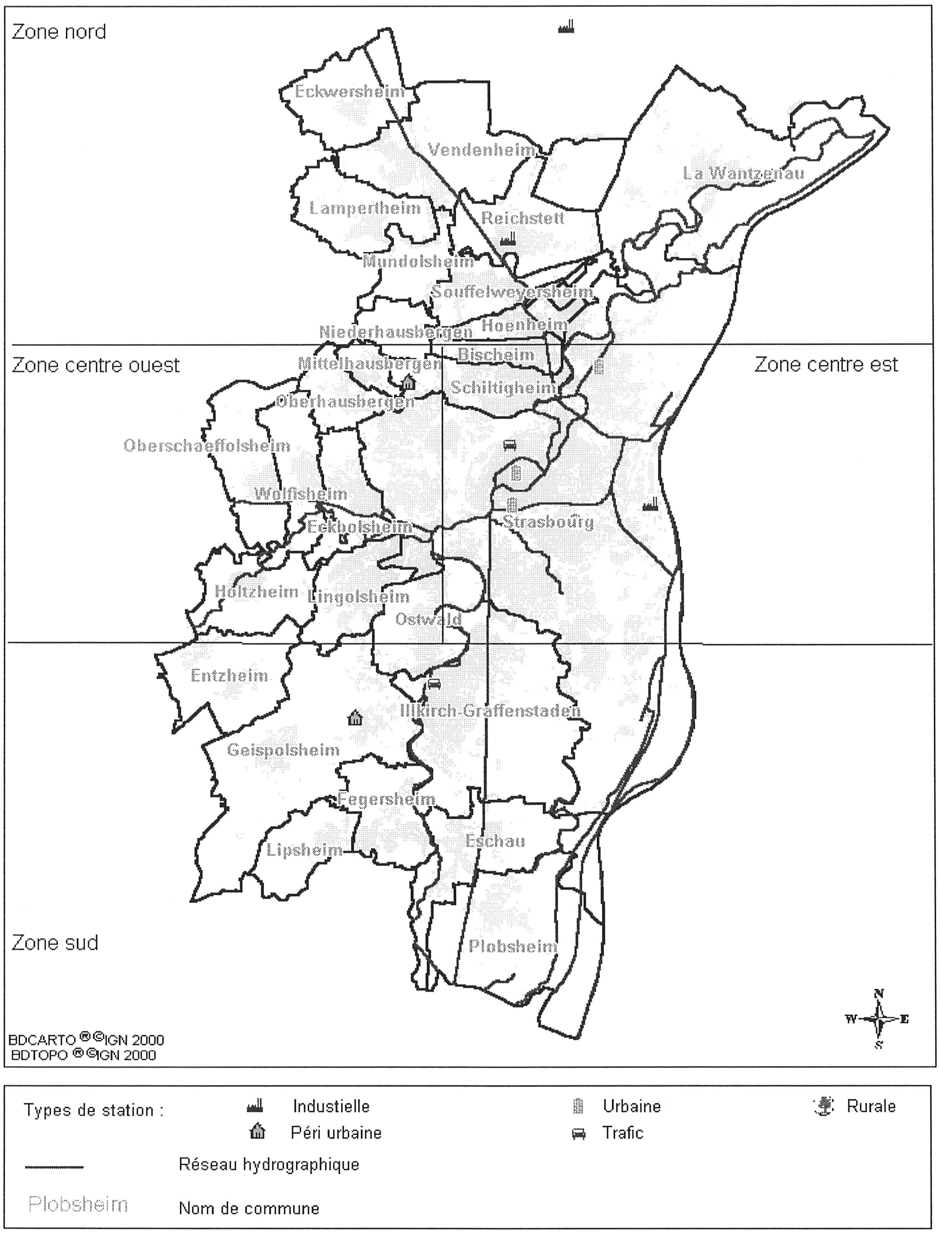
Figure 3: Volumetric descriptors.

Street modeling

The STREET software allows simulating quickly the annual means of pollutants distribution in a streets network. To run and calculate the immisions STREET uses a database gathering more than 100 000 situations defined by 3D MISCAM (wind speed...). IMPACT from ADEME on COPERT II (Computer Programme to Calculate Emissions from Road Transport) is used for the emissions calculations.

To model traffic pollution with STREET it is necessary to get a street database and some ancillary data to characterize the network and the traffic (ASPA, 2001). The data used in the model are the amount of vehicles (VL ad PL); buses, speed and traffic jam values. The type of building along the streets is necessary and of course the number of crossroads and lanes per road. The meteorological data and the pollutant measurements (NO_x, CO, COV, PM_{10} and SO_2) are also introduced.

The 27 communes of the Strasbourg urban Community are considered (figure 4). Only Strasbourg has been detailed, for the other communes only the main roads have been used. 1390 km of roads have been integrated, only the crossroads having more than 2000 vehicles/day have been identified.



Carte 1 Périmètre d'étude

Figure 4: Streets network over Strasbourg area.

Simulations have been run for each of the pollutants. The result by street segments is merged to obtain a final representation of the pollutants distribution (figure 5). The results obtained for 2000 provide some ideas about the level of air quality: an overlap of the quality threshold for C6H6 (2 $\mu g/m^3$) is noticed because of a high level of pollution (figure 5). Around 46% of the streets present an overlap of the quality value for SO_2 (2010). To complete this study statistical methods (principal component analysis) have been applied on the results providing a general behavior of the street segments. The results allow locating several streets with singular conditions. Investigations are necessary to extract more explanations.

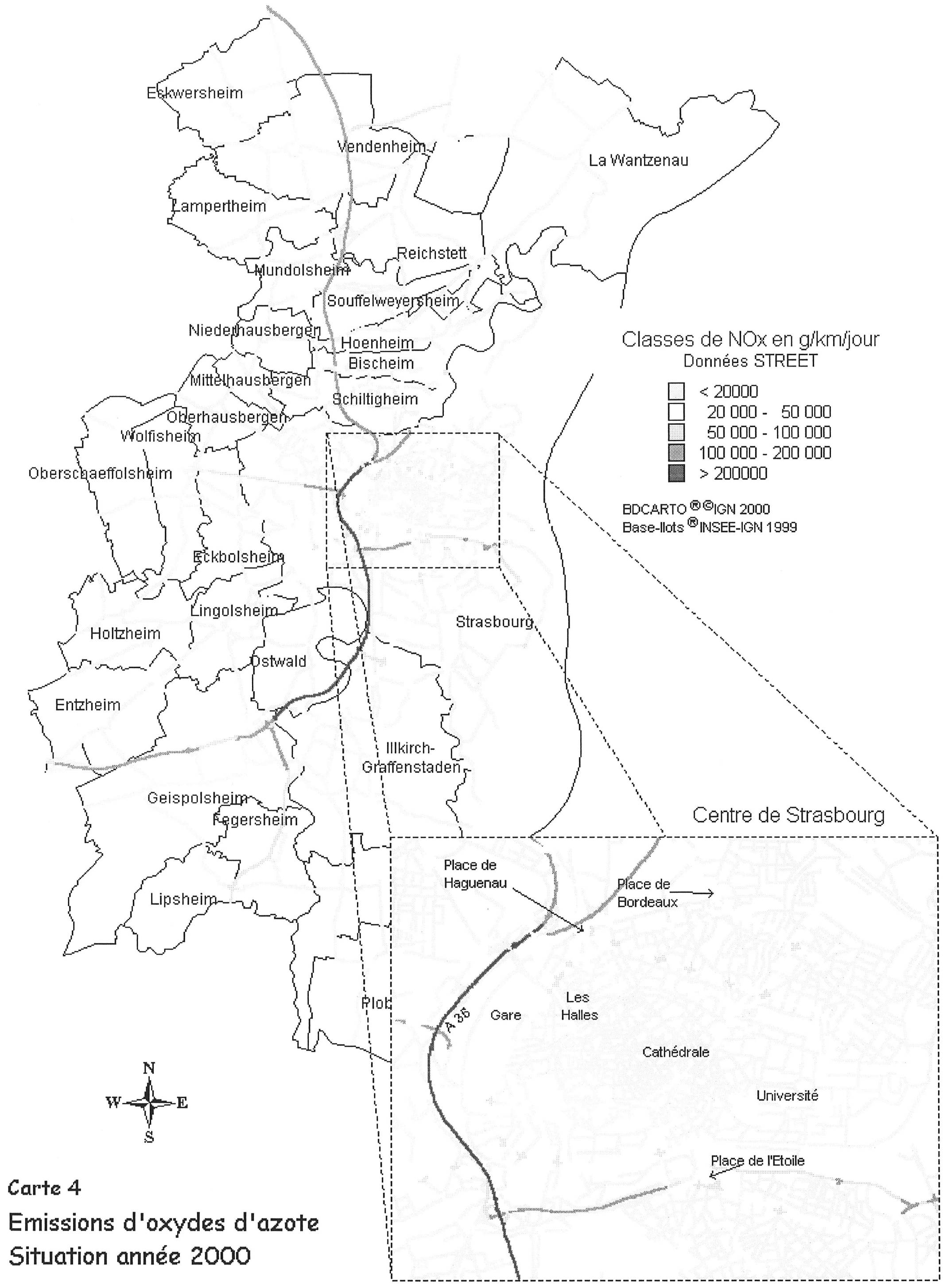
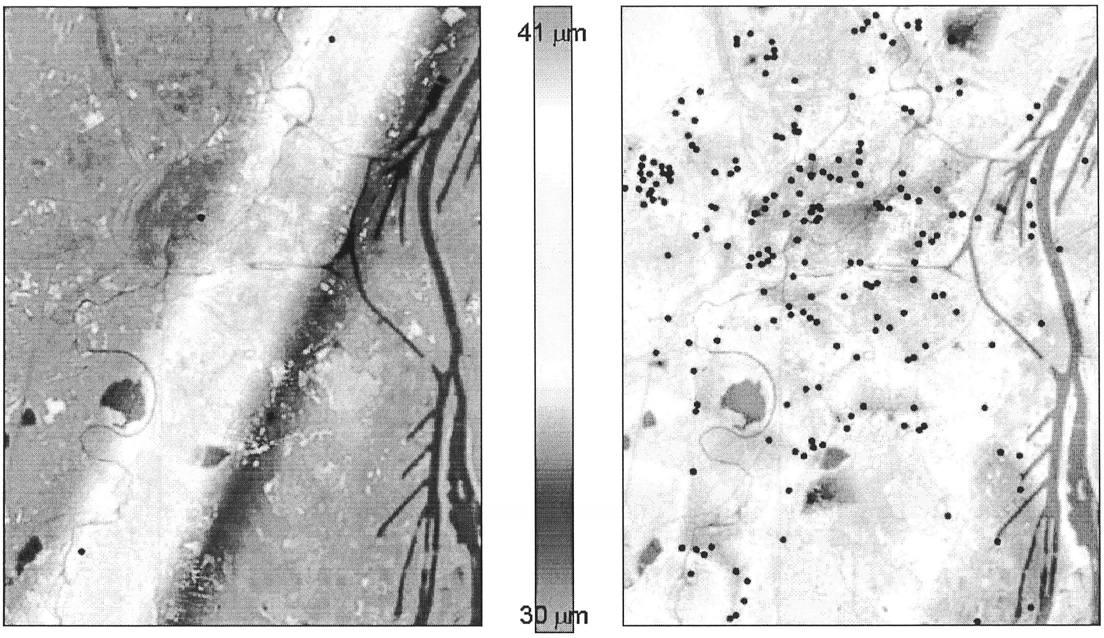


Figure 5: C6H6 representation.

Remote sensing and pollutant distribution

This methodological step is based on the complementarity of the morphological indicators, the street information and the spectral values over the area. Usual methods used for construction of maps of pollutants are interpolation/extrapolation techniques. Some are using kriging method (Frangi, J.P.,and al. 1996), others recommend the use of thin plates interpolation method (Ionescu, 1996). Figure 6a presents an example of a particulate matters (PM) map obtained with thin plates method from measures over the city of Strasbourg for March 31, 1998. In transparency is visualized the Landsat TM4 (SWIR) channel, showing the structure of the area. At this date only three measuring stations deliver information for PM. The accuracy of the method obtained depends on the accuracy of the measuring stations, if the measurement is representative of the neighborhood (Basly and Wald, 2000). In fact the position of the instruments and the quantity of measuring stations greatly influence the mapping results. Some authors encounter even high variations of the pollutant concentrations from one side of a street to the other (Croxford and Penn, 1998). For a reasonable accuracy (5% of probability error) and top obtain concentration values with an error of 20 %, Sifakis (1992) recommends 4 stations per 2.5 km^2. As the cost of a measuring station is very expensive, other solutions should be find. Using Earth observation data is one of the solutions.

Several studies have shown the possible relationships between satellite data and air pollution (Basly and Wald, 2000 ; Sifakis ; 1992 ; Basly 2000 ; Wald and Baleynaud 1999, Retalis and al., 1999). Concerning the PM, a strong correlation was found by some of these authors with the thermal infrared image of Landsat (TM6). The proposed methodology is based on this assumption. But looking for correlation between three measuring stations and measurements acquired from satellite images is not mathematically convincing. Hence it is proposed to construct a multidimensional vector for each point of the image integrating various sources of information. This vector is representative of the spectral information acquired by the satellite (it comprises the measurements done for each pixel in each spectral band except TM6) and of the morphological configuration of each pixel neighborhood (through a textural index or different other criteria (previous §). This multidimensional vector can be understood as an identity card (ID) of each pixel in the image. The ID of each pixel is then compared to the ID of the pixel corresponding to the real measuring stations. When the IDs are similar, the value of the Landsat TM6 band is considered, and a pollutant value is allocated to this pixel according a relationship. This relationship is a regression computed from all the available images (in this case three) and the pollutant measurements of the stations. This methodology allows the creation of so-called "pseudo stations" (black dots in Figure 6 a and b). It strongly improves the quantity of points of measures and allows the application of interpolation methods for computation of pollution distribution over the city. For this particular case, 4018 pseudostations were derived for the 180 km x 180 km of the Landsat image. The resulting image gives a more realistic view of the distribution of pollutants over the city. In order to validate the proposed approach, a ground-truth campaign has been organized in June 2002 combining acquisition of satellite data with 4 measurement vans distributed over the city.



a. b.

Figure 6 a and b: Pseudostation concept and representation simulation.
(a. Extract of a map of PM10 for March 31, 1998,
(b. Pollution distribution simulation).

DISCUSSION AND CONCLUSION

The use of a multiscale approach provides new elements for mapping of pollutant concentration in towns. The various modeling products allow a better spatialization of the phenomena under study. The results achieved over Strasbourg will allow:

- a better understanding of the influence of local morphology over pollution,
- validation of numerical models dealing with local pollution.
- the optimization of sitting for new measuring stations,
- the indication of areas where anti-pollution efforts should be carried out.

The next step of this part of the project research is the establishment of mathematical relations between other pollutants, such as NOx, O3, SO2, with other spectral bands measured by satellites (SPOT, Landsat, ENVISAT, IRS, IKONOS,...) and improvement of the methodology for obtaining a more complete representation and understanding of air pollution inside cities. The validation of this approach has been achieved through the ground-truth campaign organized in June 2002 and results will be exploited this autumn.

This study beneficiated and must be developed on various directions: the interactions between measure locations, surrounding areas, streets and global urban area. We have set down that some relationships might be identified and described in order to improve our knowledge on pollutant transportation and distribution. We have extracted several indicators that can be used to characterize measurement sites and the close surrounding area, in different ways. This approach has to be developed to assess measurement sites representativity inside a network but also through different networks. The fact that the location and the belonging category of a measurement site has to be analyzed with the evolution of pollution situation is rather crude, but it seems more and more obvious that this representativity over time need to be assessed continuously. These indicators are also useful to reinforce the relationships between locations and spectral values due remotely sensed data.

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